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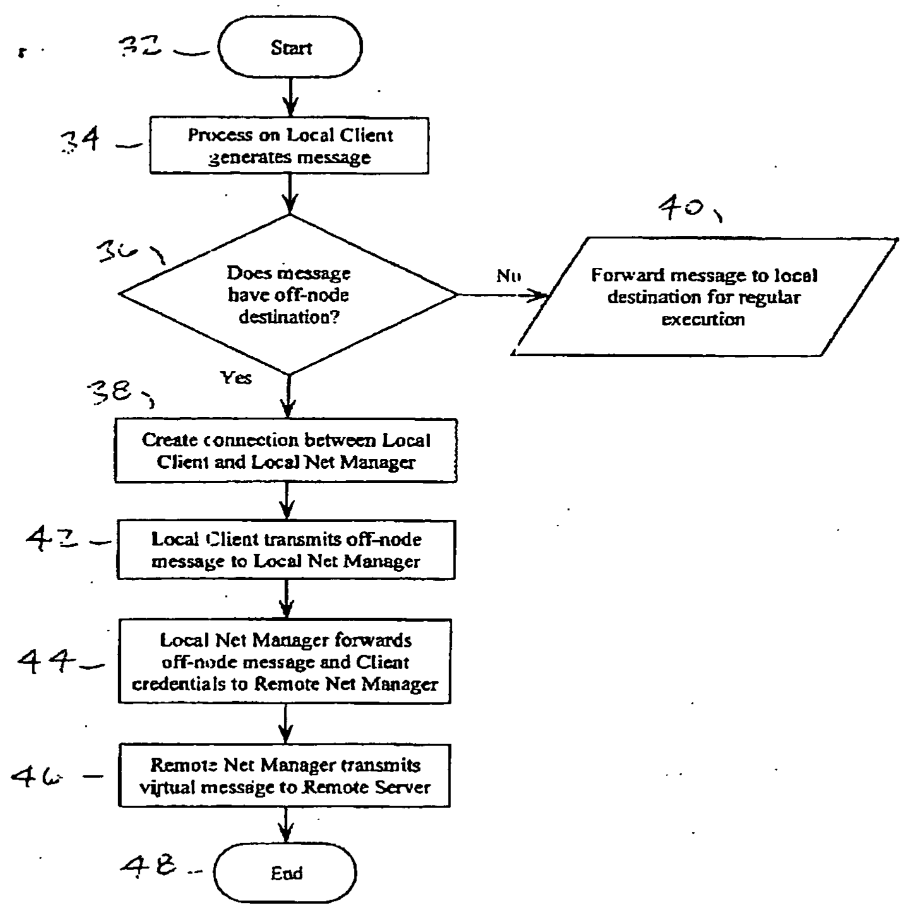
(54) **SYSTEME D'EXPLOITATION CENTRAL REPARTI**
(54) **DISTRIBUTED KERNEL OPERATING SYSTEM**



(57) The present invention relates generally to networks of computer systems, and more specifically, to a method and system of distributed operating system over a network of computer systems. Existing distrbuted operating systems have performance limits due to multiple layers, distinctions between client and server abilities, and inflexible architectures. The invention presents a system and method of distributed operating system with a single level architecture which is just as easily applied to a flexible network environment, including an internet communication link, as to a stand-alone computer. This is done by use of a message passing operating system, and by sending off-node messages to network managers which are capable of directing and receiving the off-node messages.

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ABSTRACT

The present invention relates generally to networks of computer systems, and more specifically, to a method and system of distributed operating system over a network of computer systems. Existing distrbuted operating systems have performance limits due to multiple layers, distinctions between client and server abilities, and inflexible architectures. The invention presents a system and method of distributed operating system with a single level architecture which is just as easily applied to a flexible network environment, including an internet communication link, as to a stand-alone computer. This is done by use of a message passing operating system, and by sending off-node messages to network managers which are capable of directing and receiving the off-node messages.

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The present invention relates generally to networks of computer systems, and more specifically, to a method and system of distributed operating system over a network of computer systems.

Background of the Invention

In its simplest form, computer networking provides a mechanism for sharing files and peripheral devices among several interconnected computers. Ideally, a computer network should allow all computers and applications to have access to all the resources of the network, optimizing the collective resources.

The main responsibility of an operating system (OS) is to manage a computer's resources. All activities in the computer including scheduling application programs, writing files to disk, and sending data across a network, should function together as seamlessly and transparently as possible.

Some environments call for more rigorous resource management and scheduling than others. Real time applications, for instance, depend on the operating system to handle multiple events within fixed time constraints. The more responsive the OS, the greater flexibility a real time application has to meet its deadlines.

Typically, operating systems on computer networks are provided as multi-layer systems: one layer for the local environment, and a separate layer for the network environment. This results in two different operating systems having to be learned by developers and users. As well, because the interfaces with the local and network layers are significantly different, an application program may be written for one layer or the other, but can not be written to handle both. That is, network versions of application programs may not run on individual computers and stand-alone versions may not run on networks.

Typically, network software is designed to handle client computers and servers as distinctly different machines. If a user wishes to have a central computer provide files to a number of remote computers, then the central computer must be designated as a server, and the remote computers as clients. This generally limits the flexibilty of the network, because server and client computers are given different abilities by the operating system. For example, it is not possible for two computers to share files with one another because one must be designated as the server, and the other the client Generally the server may not access files stored on the client.

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Traditional computer network systems were designed and optimized to handle a narrowly defined set of resources and configurations. For example, the typical mainframe computer system would comprise a mainframe computer with a large memory storage area and set of printers. Smaller terminals or computers would access this mainframe as clients in a manner specific to the network and software. Such computer systems do not have the flexibility to exploit such new communication developments as the internet.

Because of the large software overheads of traditional operating systems, they can not be applied to smaller computer systems such as those found in automobiles or cellular phones.

Therefore, such operating systems are not appropriate for a broad range of applications including multiprocessor systems, palm top or laptop computers which may be integrated with other larger computers, cellular telephones, automobile controllers and smart process control instruments.

There is therefore a need for a method and system of a distributed operating system that addresses the problems outlined above. This design must be provided with consideration for reliability, speed of execution, and the volume of programming code required.

Summary of the Invention

It is therefore an object of the invention to provide an improved distributed network operating system.

One aspect of the invention is broadly defined as a method of implementing a distributed operating system between a local client processor on a local network having a local message passing operating system and a local network manager and a remote server processor on a remote network having a remote message passing operating system and a remote network manager via a communication network interconnecting the local network and the remote network, comprising the steps of: the local message passing operating system responding to a message generated by the local client processor having an off-node destination by creating a connection between the local client processor and the local network manager; the local client processor transmitting the message to the local network manager via the connection; the local network manager transmitting the message and credentials of the local client processor to the remote network manager corresponding to the off-node

destination via the communication network; and the remote network manager responding to an off-node message being received by forwarding a virtual message to the remote server.

Brief Description of the Drawings

These and other features of the invention will become more apparent from the following description in which reference is made to the appended drawings in which:

Figure 1 presents a symbolic layout of the processing software in a manner of the invention;

Figure 2 presents a flow chart of the overall method in a broad manner of the invention;

Figure 3 presents a state diagram for message passing functions as known in the art;

Figure 4 presents a flow chart of the boot routine for the Client side method in the preferred embodiment of the invention;

Figure 5 presents a flow chart of the initial message routine for the Client side method in the preferred embodiment of the invention;

Figure 6 presents a flow chart of a subsequent message routine for the Client side method in the preferred embodiment of the invention;

Figure 7 presents a flow chart of an initial message routine between the Remote Network Manager and the Remote Server in the preferred embodiment of the invention; and

Figure 8 presents a flow chart of an initial message routine between the Remote Server and Remote Network Manager in the preferred embodiment of the invention.

Detailed Description of Preferred Embodiments of the Invention

The invention may be described with respect to a physical layout such as that of **Figure 1**. This layout presents a local computer system **10** and a remote computer system **12**, interconnected via a communication network **14**. The limitations of the local computer system **10** and remote computer system **12** will become clear from the description that follows, but generally, the physical arrangement and electronic components of the systems are not a limitation of the

invention. The particular layout presented is only intended as an example with which to describe the invention.

Similarly, the communication network **14** that allows message passing between the two computer systems **10** and **12**, may also take on many physical forms and various communication protocols. As the data being passed between the two computer systems **10** and **12** are simply messages, they are independent of the media used to communicate them. Therefore, the type of communication network has little bearing on the invention.

The local computer system **10** of **Figure 1** includes a local client processor **16** which may execute application programs. It is able to communicate with the other devices in its local area via a local area network which may be implemented in a manner known in the art. These local devices may include a local message passing operating system **18**, one or more local servers **20** and **22**, and a local network manager **24**.

The local message passing operating system **18** and local network manager **24** are software programs that are generally stored in an executable form on a computer readable medium such as a random access memory (RAM), read only memory (ROM), optical disk (CD-ROM) or magnetic storage medium (hard drive or portable diskette). Of course, the local operating system **18** and local network manager **24** could also be implemented by hardware means, or other means known in the art.

The local message passing operating system **18** is accessible to each of the local processors **16**, **20** and **22** . In addition to message passing as a means of interprocess control, this operating system generally provides such capabilities as data input and output, and timing services which are provided via external subroutines stored on similar memory media. Such implementations of message passing operating systems are known in the art. The message passing operating system handles communication between each of the processors **16**, **20** and **22**, and the local network manager **24** by setting up communication channels and connections between them.

The remote computer system **12** has a similar arrangement, including a message passing operating system kernel **26**, a remote server **28**, and a remote network manager **30**. In this arrangement, the three devices shown, the message passing operating system kernel **26**, remote server **28**, and remote network manager

30, are free to communicate messages between one another via a message passing network, while the remote network manager **30** may communicate with the local network manager **24** via the communication network **14**. The components of this remote network **12** will have similar features to the corresponding components in the local network **10**.

Similar to the local network **10**, the arrangement of the remote network **12** is intended only as an example with which to describe the invention. Clearly, an infinite number of arrangements may be created, which would be known to one skilled in the art. In the extreme, a network could comprise two processors on a single circuit board, interconnected so that they could communicate with one another.

A method which addresses the objects outlined above is presented as a flow chart in **Figure 2**. This method of implementing a distributed operating system may be applied between a local client processor on a local network and a remote server on a remote network, where the local and remote networks are interconnected via a communication network. Generally, the local client processor will have access to a local message passing operating system and a local network manager, and similarly, the remote server will have access to a remote message passing operating system and a remote network manager.

Such an arrangement to implement this method would be similar to that of **Figure 1**. The method starting at step **32** of **Figure 2** is shown in the form of a succinct flow chart in the interest of clarity. The method steps may clearly execute on different processors, sequentially or as part of other routines with additional steps. As well, changes could be made to the specific details of these steps to realize the invention, or to apply it to different applications.

The method comprises the local message passing operating system **18** responding to a message generated by the local client processor **16** at step **34** having an off-node destination identified at step **36**, by creating a connection between the local client processor **16** and the local network manager **24** at step **38**. If the message has an on-node address, then the message is handled in the regular manner at step **40**. Once the channel has been created, the local client processor **16** may transmit the off-node message to the local network manager **24** at step **42**, via the connection created at step **38**. The local network manager **24** may now transmit the off-node message and credentials of the local client processor **16** to the remote network manager **30** corresponding to the off-node destination via the

communication network, at step **44**. The remote network manager **30** may now pass the off-node message being received by forwarding a virtual message to the remote server **28** at step **46**. This ends the routine at step **48**.

Broadly speaking, the method of the invention provides a distributed operating system which handles message passing from the local client processor to the remote server in two stages. The client side **10**, essentially treats the local network manager **24** as an artificial server to the local client processor **16**. Similarly, the remote network manager **24** generates virtual messages which it passes to the remote server **28**; the remote network manager **30** acting like a client to the remote server **28**.

To elaborate on this method, firstly, the local and remote operating systems **18** and **26** are known in the art as message passing operating systems. In the method of the invention, message passing is the fundamental means of interprocess control (IPC) throughout the entire system. A message is a packet of bytes passed from one process to another with no special meaning attached to the content of the message. The data in a message has meaning for the sender of the message and for its receiver, but for no one else.

Message passing not only allows processes to pass data to each other, but also provides a means of synchronizing the execution of several processes. As they send, receive, and reply to messages, processes undergo various "changes of state" that affect when and for how long, they may run. Knowing their states and priorities, the operating systems **18** and **26**, can schedule all processes as efficiently as possible to optimize the available processor resources.

On the client side computer system **10**, the application running on the Local client **16** must know the off-node address of the remote server **28**. In an embodiment of the invention, the local kernel operating system **18** recognizes any message as off-node message when it does not have a corresponding local mapping for the node identification. In other words, the default is for the operating system **18** to consider unrecognized messages to be off-node, and to ~~direct such messages~~ to the Local Client's **16** connection to the local network manager **24**.

The connection that is created at step **38** can not be described without a short review of threads and processes, both of which are known in the art.

A thread is a conveniently sized collection of programming steps that are scheduled and executed as a group. A process, on the other hand, can be thought

of as a "container" for threads, defining the address space within which threads will execute. A process will always contain at least one thread.

Message passing is directed towards channels and connections, rather than targeted directly from thread to thread. A thread that wishes to receive messages first creates a channel, and another thread that wishes to send a message to that thread must first make a connection to that channel by "attaching" to the channel.

Channels are required by the message kernel calls and are used by servers to MsgReceivev() messages on. Connections are created by client threads to "connect" to the channels made available by servers. Once connections are established, clients can MsgSendv() messages over them. If a number of threads in a process all attach to the same channel, then the one connection is shared between all the threads. Channels and connections may be named within a process by a small integer identifier. Client connections may map directly into file descriptors.

A channel has three queues associated with it: one for threads waiting for messages, one for threads that have sent a message that hasn't yet been received, and one for threads that have sent a message that has been received, but not yet replied to. While in any of these queues, the waiting thread is blocked.

This message blocking generally follows the state diagram of **Figure 3**. When a process isn't allowed to continue executing because it must wait for some part of the message protocol to end, the process is said to be blocked. Briefly, a thread that transmits a MsgSendv() to another thread, which could be within another process, will move from the Ready State **50** to the Send Blocked State **52** until the target thread transmits a MsgReceivev() back, putting the thread into a Reply Blocked State **54**. Then, when the target thread has processed the message and transmitted a MsgReplyv(), back to the originating thread, it returns to the Ready State **50**. If a thread executes a MsgReceivev() without a previously sent message pending, it will be Receive Blocked **56** until the target thread transmits a MsgSendv() back to the originating thread. This blocking maintains the synchronized execution of the threads.

As will be described in more detail later, the client side **10** retains this blocking scheme, so threads are processed in the manner described above. In the preferred embodiment, this blocking scheme is modified on the server side **12** so threads are queued as they arrive to ensure proper sequence of execution.

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Returning now to the method of the invention, the manner of implementing regular execution of threads per step **40** is well known in the art and will not be described herein. Various means of implementing the transmission of the message between the local client processor **16** and the local network manager **24** per step **42** would also be known to one skilled in the art. Clearly the invention is not limited to the transmission via the channels and connections discussed above.

It should be noted that the term "transmission" has been used to describe the transfer of a message from one device to another. The term is intended as a generalization and to prevent confusion with the message types "send" and "receive".

As noted above, the communication channel **14** between the local and remote network managers **24** and **30**, may take a number of manners as known in the art, as only a message need be communicated. For example, the transmission of step **44** may be implemented using a TCP/IP protocol network.

Also as noted above, the remote network manager **30** wishes to present itself as a client to the remote server **28**, at step **46**. It does this by creating a virtual message, that is, a message created from the off-node message but directed back to the remote network manager **30**, rather than to the local client processor **16**. The remote network manager **30** keeps a record of the virtual messages it has created, so that it can return the response from the remote server **28** to the local network manager **24** as a properly addressed message that will be routed to the correct client processor on the client side **10**. The routine is then completed at step **48**.

As noted in the Background to the Invention, simple local area networking provides a mechanism for sharing files and peripheral devices among several interconnected computers. The method of the invention goes far beyond this simple concept and allows integration the entire network into a single, homogeneous set of resources.

Any process on any machine in the network can make use of any resource on any other machine. From the application program's perspective, there is no difference between a local or remote resource and no special facilities need to be built into applications to allow use of remote resources. In fact, an application program would need special code to be able to tell whether a resource such as a file or device resides on the local computer or on some other node on the network.

Users may access files anywhere on the network, take advantage of any peripheral device, and run applications on any machine on the network provided they have the appropriate authority. Processes can communicate in the same manner anywhere throughout the entire network.

The invention provides for a single layer operating system which allows seamless implementation of the local operating system in a network environment. This reduces the learning curve required of developers and users.

As well, the invention requires minimal code modifications for local application programs to be operated in the network environment. The minimal code changes result in little impact on the existing speed of execution, reliability and volume of programming code in the application program.

The software in the two network managers **24** and **30**, is the same, and is not specific to either server or client. This allows each device to have the same privileges, and for access between the two networks to be bi-directional. This also allows greater flexibility of system configuration and allows greater optimization of the system resources.

The preferred embodiment of the invention will now be described, first with respect to the client side **10**, and then with respect to the server side **12**.

As far as the local client processor **16** is concerned, there is no difference between a connection through the Local Net Manager **24** to a remote server **28**, and a connection to a same-node server such as **20** or **22**, except perhaps a lower speed, depending upon the communication medium **14**.

The Local Net Manager **24** component blocks the local client processor **16** as per normal messaging, and communicates the off-node message to the Remote Network Manager **30** on the specified remote node. When the two network Managers **24** and **30** have completed the message transaction using the Send/Receive/Reply sequence, the Local Net Manager **24** unblocks the local client processor **16**.

Operation of the Client Side **10** in the preferred embodiment of the invention is described with respect to **Figures 4**, **5** and **6**. **Figure 4** presents in a flow chart, the steps that occur during initialization, starting at step **58**. The Local Network Manager **24** has a standard channel on which it receives messages. In the preferred embodiment of the invention, this channel identification is created and identified to the kernel as the "network channel identification" when the Local Network Manager

24 issues a ChannelCreate() kernel call at step **60** containing a special flag indicating that it is a network manager.

At step **62**, the local kernel creates the network channel **64** on the Local Network Manager **24**. Generally such initializations are executed at the start or boot up of the system, but the initializations need not be executed until they are required. As well, other initializations are generally executed as part of this routine, such as variable declarations and the creation of other channels, but they are not pertinent to the invention. Thus, the initialization routine required for the Client side system **10** ends at step **66**.

Figure 5 presents a flow chart of the handling of an initial message on the Client System **10** in the preferred embodiment of the invention, starting with step **68**. The local client processor **16** creates a connection to the Local Network Manager **24** by issuing a ConnectAttach() to the operating system kernel **18** at step **70**, having a node identification (nid) that is non-zero and that is different than the local client processor's **16** node identification. The kernel **18** receives the ConnectAttach() call, and looks at the nid at step **72**. If it is different from the kernel's **18** node identification, the local kernel transmits a connection identification (coid) to the Local Client **16** that points to the remote target with that off-node identification, but locally points at the Local Net Manager **24**. This is done at step **74**.

If the kernel identifies the node identification at step 72 to be non-network, which would be done by the local client processor **16** specifying a ConnectAttach() having a nid of either zero, or the value of the current node identification, a process identification (pid) and a channel identification (chid), the kernel would return an on-node connection identification (coid) at step **76**. In either case, the kernel returns a connection identification (coid) to the local client processor **16** which allows the local client processor **16** to direct messages to the desired server.

In the off-node case, the local client processor **16** actually received a coid that allows it to communicate with the Local Net Manager **24**. Any messages sent by the local client processor **16** will arrive at the Local Net Manager **24**, and it will then be up to the Local Net Manager **24** to MsgReplyv() to the local client processor's **16** messages to unblock the local client processor **16**. In effect, the Local Net Manager **24** acts as an intermediary between the local client processor **16** and the remote server **28**, though the local client processor **16** sees Local Net Manager **24** as the destination.

Note that nothing happens when the local client processor **16** initially connects to the Local Net Manager **24** using the ConnectAttach(). Only when the local client processor **16** actually sends a message using the MsgSendv() call at step **78**, does the Local Net Manager **24** do anything.

In order for the messages exchanged by the Local Net Manager **24** and Remote Network Manager **30** to be delivered to the correct destination, both the Local Net Manager **24** and Remote Network Manager **30** must have at least indirect knowledge of the local client processor **16** and the remote server **28**. This is performed via an internal handle and a receive ID.

At step **80**, the receive ID is obtained by the Local Net Manager's **24** MsgReceivev() message when the local client processor **16** performs the MsgSendv(). The receive ID is sent from the Local Net Manager **24** to the Remote Network Manager **30** via a NTONET_CONNECT_CRED message, and is then stored on the Remote Network Manager **30**.

Note that the local client processor **16** is still Reply blocked at this point, awaiting a Reply from the local network manager **24**. Also, note that the local client processor's **16** credentials were sent to the remote network manager **30** as part of the initial NTONET_CONNECT_CRED message.

"Credential" information is simply information about who the local client processor is, and may include a real user ID, an effective user ID, a saved user ID, a real group ID, effective group ID, saved group ID, number of groups or number of supplementary groups.

If the local client processor's **16** credentials change between the time that the connect message was sent and another message is sent, the Local Net Manager **24** must inform the Remote Network Manager **30** of that change. As part of the functionality of the ChannelCreate()'s _NTO_CHF_NET_MSG flag, the kernel **18** tracks changes to the local client processor's **16** credentials.

Whenever the Local Net Manager **24** performs a MsgReceivev() and specifies the struct _msg_info info parameter at step **82**, the kernel **18** will set the flag member to _NTO_MI_NET_CRED_DIRTY at step **84** if the local client processor's **16** credentials have changed. Note that this credential change flag is automatically cleared when read via MsgReceivev().

The Remote Network Manager **30** generates an internal handle for its own use. The internal handle and the server connection ID from the Remote Network

Manager **30** to the remote server **28** are returned in the reply message to the Local Net Manager **24** called NTONET_CONNECT_SUCCESS.

The scoid from the Remote Network Manager **30** to the remote server **28** is then stored by the Local Net Manager **24** in the local client processor's **16** space via NetInfoscoid(), for use later by functions such as ConnectServerInfo().

If the communication has been successful, as determined at step **88**, then a NTONET_CONNECT_SUCCESS is returned to the Local network Manger **24** at step **90**. Otherwise, an error message is returned at step **92**. The routine for an initial message is then complete at step **94**.

In the initial implementation of the invention, the entire message will be transferred from the Local Net Manager **24** to the Remote Network Manager **30**, avoiding any complications on the Local Net Manager **24** and Remote Network Manager **30** sides. To do this, the lower transport layers are passed the rcvid from the local client processor **16**, and it is up to those layers to fetch and transmit the local client processor's **16** data. After the data has been queued for transmission to the remote node, the Local Net Manager **24** returns to the MsgReceivev(), awaiting the next message.

Conversely, when a message arrives from the Remote Network Manager **30**, the network transport layer performs a call back to the Local Net Manager **24**. It is up to the Local Net Manager **24** to MsgReplyv() with the message contents to the local client processor **16**.

Although the Local Net Manager **24** and the Remote Network Manager **30** are being described as separate components, they may be identical, allowing two-way network communication. In such an implementation, there is no "server" or "client" version of the software; both client side **10** and server side **12** messages will arrive from the transport layer, and the MsgReceivev() will handle not only client requests, but server requests as well.

Subsequent messages are handled in the same manner, as outlined in the flow chart of **Figure 6**, starting at step **96**. When the local client processor **16** transmits a message to the Local Net Manager **24** at step **98**, it will be routed via the connection and channel as described herein above. The Local Net Manager **24** will then determine at step **100** whether the local client processor **16** has already talked to the Local Net Manager **24**.

If the local client processor **16** had not yet talked to the Local Net Manager **24**, then a structure called a network client token (NCT) is created at step **102** that describes the local client processor **16** to the Local Net Manager **24**. The NCT is filled with the true nid, pid, chid that the local client processor **16** was attempting to send the message to, as well as other information obtained from both network managers **24** and **30**. This involves the NTONET_CONNECT_CRED message being exchanged between the two network managers **24** and **30**. If there had already been communication then there will exist a network client token (NCT) that describes the local client processor **16** to the Local Net Manager **24**.

The Local Net Manager **24** then determines whether the local client processor's **16** credentials have changed at step **104**. If so, then the local net manager **24** will transfer a NTONET_MSGSEND_CRED to the remote net manager **30**, including the revised credentials at step **106**, rather than a NTONET_MSGSEND at step **108**. The transfer of subsequent messages on the client side **10**, then ends at step **110**.

The Local Net Manager **24** performed a MsgReceivev() to await messages. One of the following messages will arrive: a message from a local client processor **16** intended for an off-node server **28**, a pulse from a local client processor **16** to off-node server **28**, or a pulse from the kernel **18**. It is also possible to get a call back from the NETMGR (the low-level transport layer) as a result of a message from the Remote Network Manager **30** arriving.

The preferred embodiment of the invention will now be described with respect to the Server Side **12** implementation, as shown in **Figures 7** and **8**.

While the local client processor **16** had to invoke ConnectAttach() with different values of node identification (noid) to establish a network or local connection, the remote server **28** does not have to do anything different to handle network versus local client connections. The only difference between local and network messages that the remote server **28** would be able to detect in a message is the value of the rcvid. In the local case the rcvid is actually a combination of the client's scoid and tid, while in the network case the rcvid contains the remote network manager's scoid and a virtual thread identification (VTID), which will be described hereinafter.

The Remote Network Manager **30** consists of a main message handling loop, and a transport layer call back. The main message handling loop is responsible for

getting messages from the remote server **28** and the transport layer call back is responsible for getting messages from the Local Net Manager **24** over the communication network **14**.

The Remote Network Manager **30** also has a special interface with the kernel **26** which it uses to convince the remote server **28** that it is the client. In order to handle multiple network accesses, the Remote Network Manager **30** must be identified as one client to one remote server, and another client for another server. There are a number of ways of accomplishing this, but the preferred method is the one which is most consistent with the known design of messaging passing operating systems.

In general, kernel calls that require the remote server **28** to obtain information or data about the local client processor **16** (and not the remote network manager **30**) are either changed into messages, or are rerouted to get the information from a different location. The kernel calls that are different on the Server Side **12** may be summarized as follows:

MsgReceivev()

Not really different from the remote server's **28** perspective, but the corresponding MsgSendv() on the Remote Network Manager **30** is now a non-blocking call.

MsgWritev()

Data is not written to the Remote Network Manager **30** as would ordinarily be the case, but rather, the MsgWritev() is converted into a REPLY-blocking call that sends a pulse to the Remote Network Manager **30**. The Remote Network Manager **30** then gets this pulse and performs the MsgWritev() functionality.

MsgDeliverEvent()

The kernel **26** converts the MsgDeliverEvent() call into a REPLY-blocking call that sends a pulse to the Remote Network Manager **30**. The Remote Network Manager **30** then fetches the structure SigEvent from the Remote Server **28** and delivers it to the Local Net Manager **24**, which then calls MsgDeliverEvent() locally.

MsgReplyv()

Since the Remote Network Manager's **30** MsgSendv() was non-blocking, special attention will be required for the MsgReplyv(). It is converted into a

REPLY-blocking call that sends a pulse to the Remote Network Manager **30**, telling it that the remote server **28** has performed a Reply operation.

Referring now to **Figure 7**, the preferred embodiment of the invention will be described with respect to a message being passed to the remote server **28** on the server side **12**, starting at step **112**.

As described above, the routine begins with the local client processor **16** sending a message via MsgSendv() to the Local Net Manager at step **114**. If the Local Net Manager **24** determines that the local client processor **16** has never communicated with it before, it sends a NTONET_CONNECT_CRED message to the Remote Network Manager **30** to establish an identification for this session at step **118**.

In response to this message, the Remote Network Manager **30** allocates an internal data structure, and creates a special connection to the remote Server **28** at step **120**. This connection between the is special in two ways.

Firstly, calling NetCred() associates information about the local client processor **16** and the ultimate client process, within the connection itself. The NetCred() function effectively creates a netcred table entry which allows the kernel **26** to determine whether special handling versus regular handling should occur. Note that this table does not contain the per-thread information about the local client processor **16**, but per-process information.

Secondly, the Remote Network Manager **30** uses a _NTO_SIDE_CHANNEL flag to ensure that its connection ID to the remote server **28** allows a reply-reversed rcvid to be obtained from the kernel **26**, to be constructed from the net_coid + server_TID that did the Reply. This allows the kernel **26** to convert the remote server's **28** MsgReplyv() and MsgWritev() messages into Send messages back to the Remote Network Manager **30**, allowing the Remote Network Manager **30** to then use that rcvid for subsequent operations.

If the local net manager **24** determines at step **116** that prior communication had already been performed, then the internal data structure and special connection will already exist, so it is sufficient to pass the message on to the Remote Network Manager **30** using the NTONET_CONNECT message shown at step **122**.

In either case, once the special connection has been established, the Remote Network Manager **30** is free to send a message to the remote server **28**.

As noted above, in the preferred embodiment, the Remote Network Manager **30** has received the entire message into its buffers. Thus, when the Remote Network Manager **30** contacts the remote server **28** with the message, the Remote Network Manager **30** is prepared to transfer the entire message.

In order not to consume threads excessively, the MsgSendv() call was modified to detect whether or not it should block. If no netcred entry is identified at step **124**, then the message will be considered to be local, and the MsgSendv() functions normally at step **126**, Send blocking the thread at the Remote Network Manager **30**.

If there is a netcred entry, then the message will be considered to be a network message, and the MsgSendv() from the Remote Network manager **30** to the remote server **28** at step **128** becomes non-blocking.

In order to send this message, the kernel **26** must be given an object or messaging agent that it can track, in order to enqueue the message onto the remote server **28**. Therefore, for network message, a virtual thread identification (VTID) must be prepared at step **130**. There will be one VTID for every nid/pid/tid/coid combination. Note that in the non-network, blocking MsgSendv() case, the tid of the sender would serve as the message agent.

Since the MsgSendv() is non-blocking, the two parameters replyIOV and replyParts ordinarily used for the reply, are available for other purposes. In this case, it is preferred that the replyParts be used to contain the VTID, though other parameters may be used..

The remote server **28** now receives the MsgSendv() and queues the message in the Send queue of the incoming channel for handling at step **132**, and the routines ends at step **134**.

Referring now to **Figure 8**, the preferred embodiment of the invention will be described with respect to a message being returned from remote server **28** on the server side **12**, starting at step **136**.

The message returning from the remote server **28**, MsgWritev(), must travel to the local client processor **16**, and not just the Remote Network Manager **30**. The same condition applies to a MsgReplyv() from the remote server **28**, with the additional condition that since the Remote Network Manager **30** never blocked the MsgSendv() to the remote server **28**, the remote server **28** is not in a position to unblock the Remote Network Manager **30** via MsgReplyv(). The MsgReply() case

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will be described as it is more complex, and the MsgWritev() case follows logically from the same description.

When the remote server **28** transmits a MsgReplyv() to the rcvid at step **138**, the scoid component of the rcvid points to the remote network manager's **30** connect structure.

If the remote network manager's **30** connect structure does not have a netcred associated with it at step **140**, the kernel **26** will identify the message as a non-network message and cause normal execution to continue at step **142**.

If the remote network manager's **30** connect structure does have a netcred associated with it at step **140**, then the kernel **26** will identify the message as a network message and cause special handling to commence by causing the server thread to become Reply blocked on the Remote Network Manager **30** at step **144**. This step effectively transforms the MsgReplyv() or MsgWritev() message from the remote server **28** into a REPLY blocked state, without actually transferring a message to the remote network manager **30**.

At step **146**, the kernel **26** then enqueues a pulse on the remote network manager's **30** channel telling it that something needs to be done. A pulse is a fixed-size, non-blocking message that carries a small payload, typically four bytes of data plus a single byte code, and are generally used as a notification mechanism within interrupt handlers. They may also allow servers to signal clients without blocking on them.

The queued pulse contains information about what needs to be done, and also contains the rcvid that the Remote Network Manager **30** should use to perform MsgReadv() to get the data component from the remote server **28**.

At step **148**, the Remote Network Manager **30** then transmits a MsgReplyv() to the remote server **28** on the pulse-delivered rcvid. This MsgReplyv() is of zero length, as there is no need to transfer data. The routine is then complete at step **150**.

The Remote Network Manager **30** knows where to forward the actual reply data to because of the VTID, which was contained in the struct _msg_info (coid member) sent as a result of the pulse. The VTID contains per-client-thread information telling it where to go.

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The messages referred to herein, may be summarized as follows:

Connection Oriented Messages which are used to administer communication between the Local Network Manager **24** and the remote network manager **30**:

NTONET_CONNECT_CRED

Used to establish a connection from a local client processor **16** on the Local Net Manager **24** to a remote server **28** on the Remote Network Manager **30**, passing the local client processor's **16** credentials.

NTONET_CONNECT_SUCCESS

Used to indicate a successful response to the NTONET_CONNECT_CRED message.

NTONET_CONNECT_FAIL

This message is used to indicate an unsuccessful response to the NTONET_CONNECT_CRED message.

NTONET_DISCONNECT

Indicates local client processor **16** has disconnected from the Local Net Manager **24**.

Pulse Transport Messages which are used to carry events that would have been delivered by the kernel locally to the indicated target in the non-networked case. In the network case this data must be transmitted over the communication network **14**, and then deliver it in a manner identical to the local case.

NTONET_EVENT

Used to send a message from the Remote Server **28** back to the local client processor **16** without blocking.

NTONET_UNBLOCK

Used to indicate what the new state of the thread is that was just unblocked, therefore requiring a status to be returned. This message could indicate, for example, whether the remote server **28** actually did allow the unblock to occur.

Data Transport Messages which actually transfer message data: –

NTONET_MSGSEND

This is what the local client processor's **16** MsgSendv() data is carried by to the remote server **28**.

NTONET_MSGSEND_CRED

Same as NTONET_MSGSEND, but also transfers the local client processor's **16** credentials. This would typically be used if the local client processor **16** changed credentials after the Local Net Manager **24** sent the initial message (the NTONET_CONNECT_CRED) to the Remote Network Manager **30**.

NTONET_MSGREPLY

This is used to carry the data from the remote server **28** back to the local client processor **16**, and is invoked as part of the Remote Network Manager **30** handling of the remote server's **28** MsgReplyv().

NTONET_MSGREAD

The Remote Network Manager **30** uses this message to satisfy the remote server's **28** MsgReadv() call, by requesting additional data from the local client processor **16**.

NTONET_MSGREAD_SUCCESS

Indicates to the Remote Network Manager **30** that the Local Net Manager **24** was able to return data as a result of the SS's NTONET_MSGREAD, and contains the data.

NTONET_MSGREAD_FAIL

Indicates to the Remote Network Manager **30** that the Local Net Manager **24** was unable to return data as a result of the Remote Network Manager's **30** NTONET_MSGREAD message.

NTONET_MSGWRITE

This is what the Remote Network Manager **30** sends in order to satisfy the server's MsgWritev() call, by transferring data from the server's buffers to the local client processor **16**.

Receiving and Processing Pulses are fixed-sized non-blocking messages which carry a small payload. They are generally used as a modification mechanism within interrupt handlers. They also allow servers to signal clients without blocking on them. Since a pulse will only be arriving from the kernel, the Local Net Manager **24** knows that it can only be one of the following:

_PULSE_CODE_DISCONNECT

For all handles that were associated with the local client processor **16**, send network messages to the Remote Network Manager **30** stating that each NCT has disconnected. Remove the NCTs from the Local Net Manager's **24**

table. In case there were any messages queued in the Local Net Manager **24** to go out the network connection **14**, these are dequeued and MsgReplyv()'d to with an error return code.

_PULSE_CODE_UNBLOCK

If the local client processor **16** currently has an NCT (meaning that there exists that client/server pair), and if there is an outgoing queued message for that particular rcvid dequeue the message and MsgReplyv() to the local client processor **16**. If there is an NCT, but no queued message for that rcvid, send a NTONET_UNBLOCK message to the Remote Network Manager **30**, because by definition, we know that there is an outstanding message at the server side **12**.

Optionally, the method and system of the invention may be implemented with additional features not specifically described herein. In view of the invention as disclosed, it would be clear to one skilled in the art how to incorporate these additional features and options. Such features could include:

1. Real time implementation. Because the invention requires very little additional code and requires little additional time to execute, the invention is easily applied to real time implementations.

   For a real time implementation, it would be preferred to include the thread scheduler in the operating system kernel. Because the time required for kernel calls is so short, the small reduction in accessibility to the kernel would be made up for by the improved speed of execution in having the thread scheduler in the kernel.

2. Updating cache data only when other transmissions are made. Since updated cache data is only needed when a new transmission is made, it is not necessary to continuously update the cache data. Instead, the cache can be updated by including the update with the next new transmission.

3. Network acknowledgements are also a burden to network communication. Rather than consuming network resources by continuously transmitting updates, such data may be transmitted along with other network traffic. If a large number of network acknowledgements are outstanding, they may be collected and transmitted as a single batch acknowledgement, again saving network resources.

4. Reply messages may be used as the only means of messaging to avoid being Receive blocked on Send messages.
5. Addresses may be defined as 128 bits so that they are compatible with IPv6 internet addressing. This would allow network addresses to use standard internet Universal Resource Locators (URLs) and their associated features.

While particular embodiments of the present invention have been shown and described, it is clear that changes and modifications may be made to such embodiments without departing from the true scope and spirit of the invention. For example, modifications to larger or monolithic operating systems could be made to apply the teachings of the invention and realize performance improvements. As well, hybrids of the message passing system of the invention with existing operating systems may be appropriate to particular applications.

The operating system of the invention could be embedded into a micro controller, digital signal processor or intelligent instrumentation, operating as a piece of electronic hardware or as part of the electronic system. The invention could also be implemented in the form of machine executable software; the method of the invention being transmitted as electronic signals, or stored in machine readable or executable form in random access memory (RAM), read only memory (ROM), optical disk (CD-ROM) or magnetic storage media (hard drive or portable diskette).

An operating system in a manner of the invention could be applied to a broad range of applications, including stand-alone uniprocessor systems, multiprocessor or network-connected systems, servers, palm top or laptop computers, cellular telephones, automobile controllers and smart process control instruments. Since the invention offers the best possible utilization of available CPU cycles, it's ideal for very high-end real-time applications such as high-capacity telecom switches, image processing, and aircraft simulators.

Again, such implementations would be clear to one skilled in the art, and do not take away from the invention.

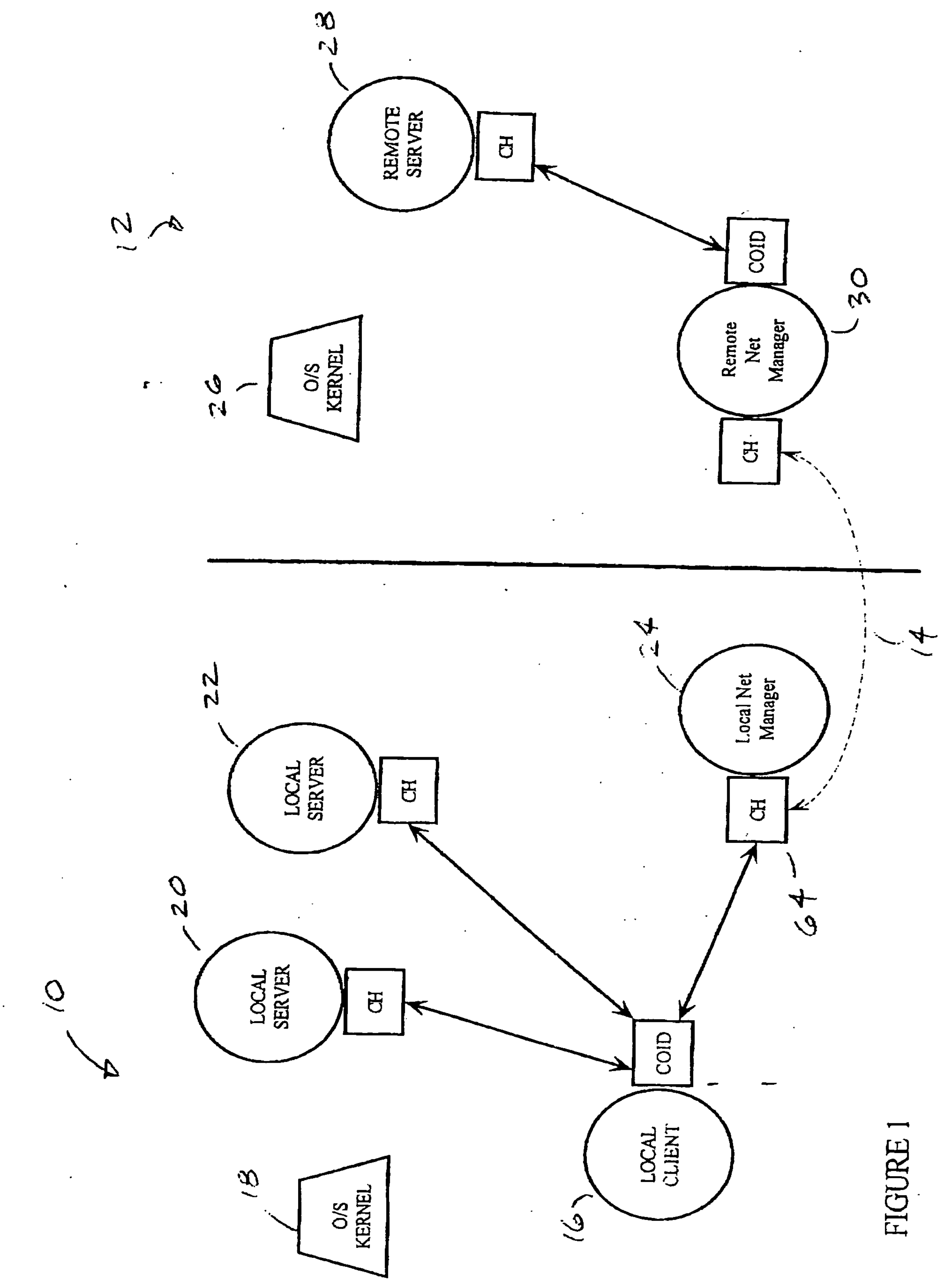
REMOTE SERVER
CH
COID
Remote Net Manager
CH
O/S KERNEL
LOCAL SERVER
CH
LOCAL SERVER
CH
Local Net Manager
CH
COID
LOCAL CLIENT
O/S KERNEL
10
12
14
16
18
20
22
24
26
28
30
64

FIGURE 1

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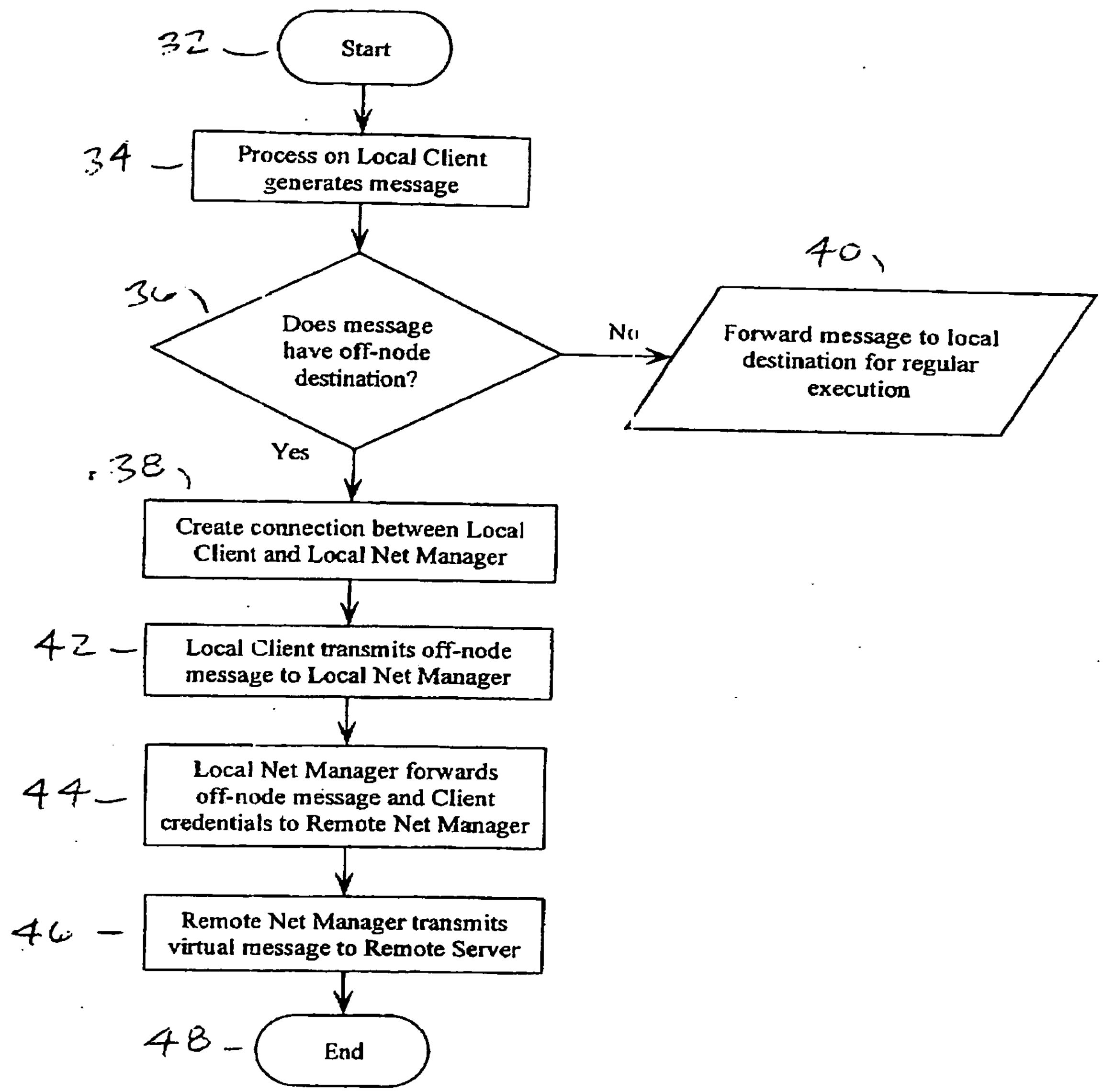

FIGURE 2

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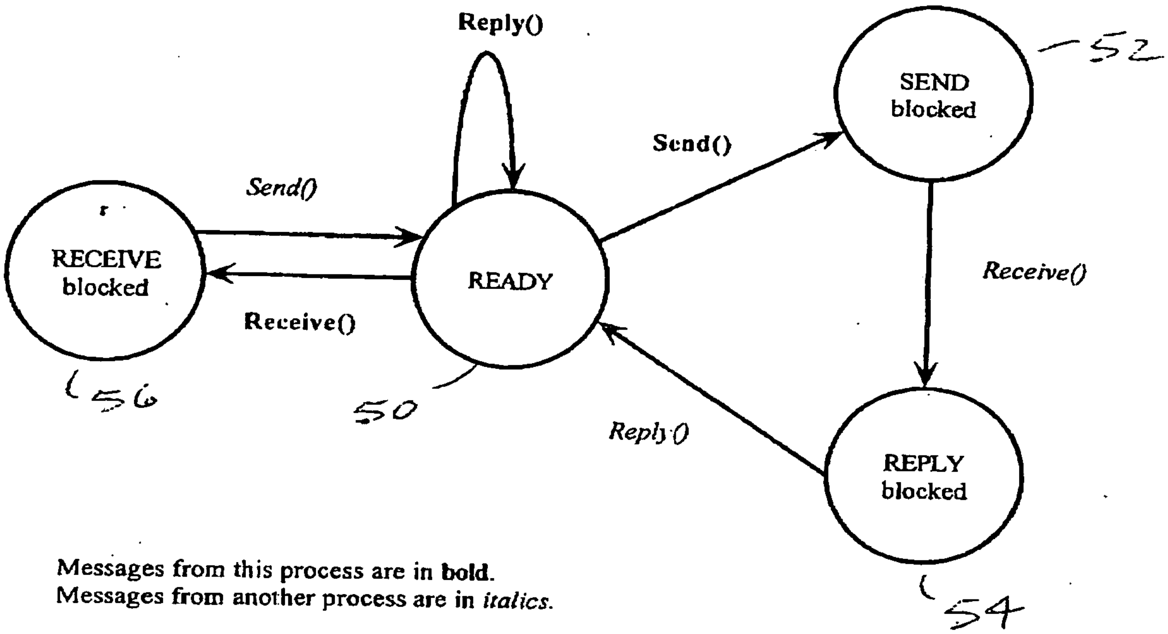

Messages from this process are in **bold**.
Messages from another process are in *italics*.

FIGURE 3

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FIGURE 4

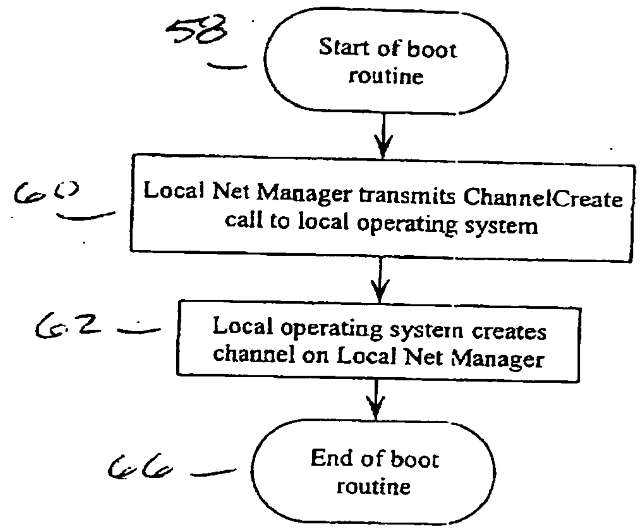

FIGURE 5

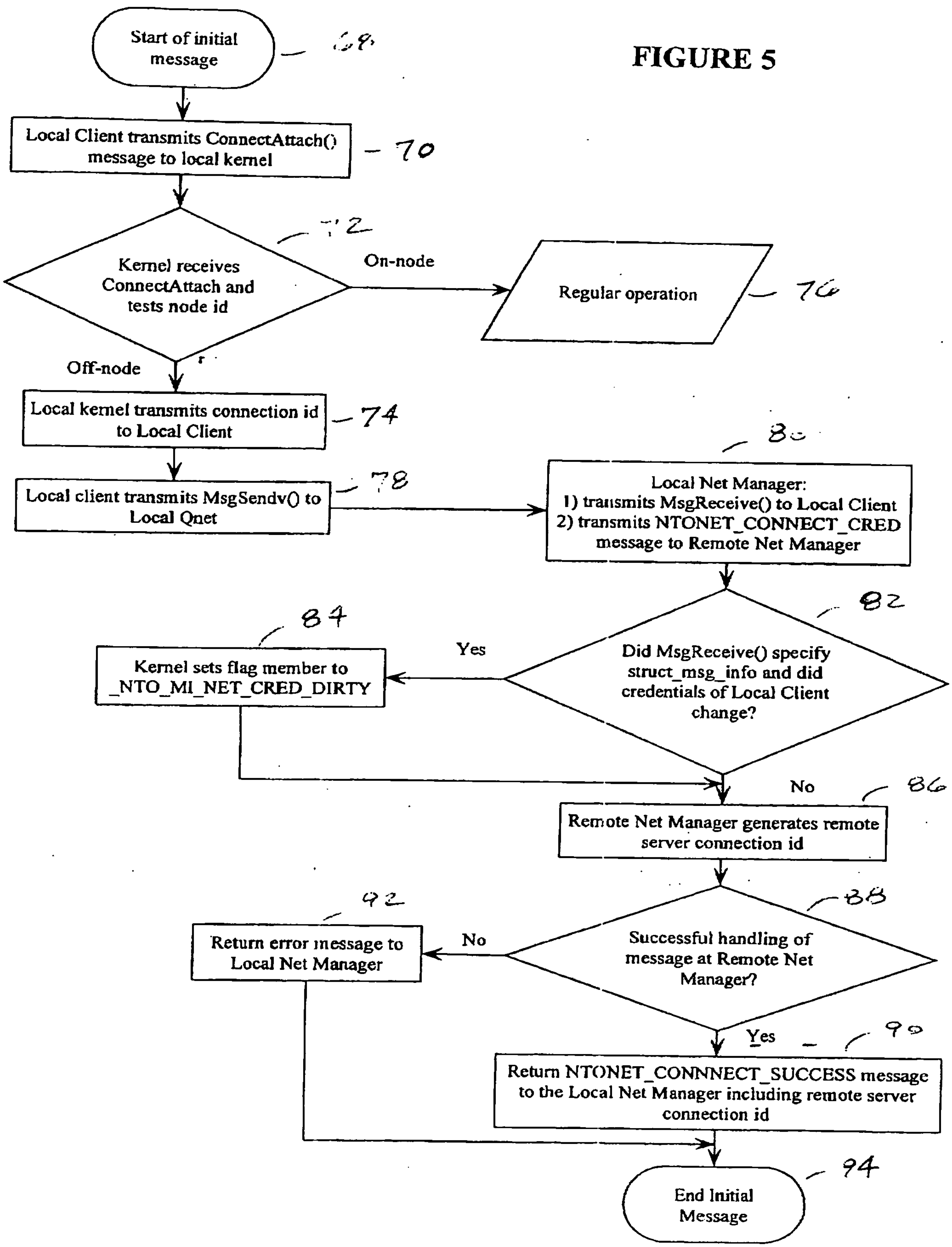
Start of initial message
68
Local Client transmits ConnectAttach() message to local kernel
70
72
Kernel receives ConnectAttach and tests node id
On-node
Regular operation
76
Off-node
Local kernel transmits connection id to Local Client
74
Local client transmits MsgSendv() to Local Qnet
78
80
Local Net Manager:
1) transmits MsgReceive() to Local Client
2) transmits NTONET_CONNECT_CRED message to Remote Net Manager
84
Kernel sets flag member to _NTO_MI_NET_CRED_DIRTY
Yes
82
Did MsgReceive() specify struct_msg_info and did credentials of Local Client change?
No
86
Remote Net Manager generates remote server connection id
92
88
Return error message to Local Net Manager
No
Successful handling of message at Remote Net Manager?
Yes
90
Return NTONET_CONNNECT_SUCCESS message to the Local Net Manager including remote server connection id
94
End Initial Message

FIGURE 6

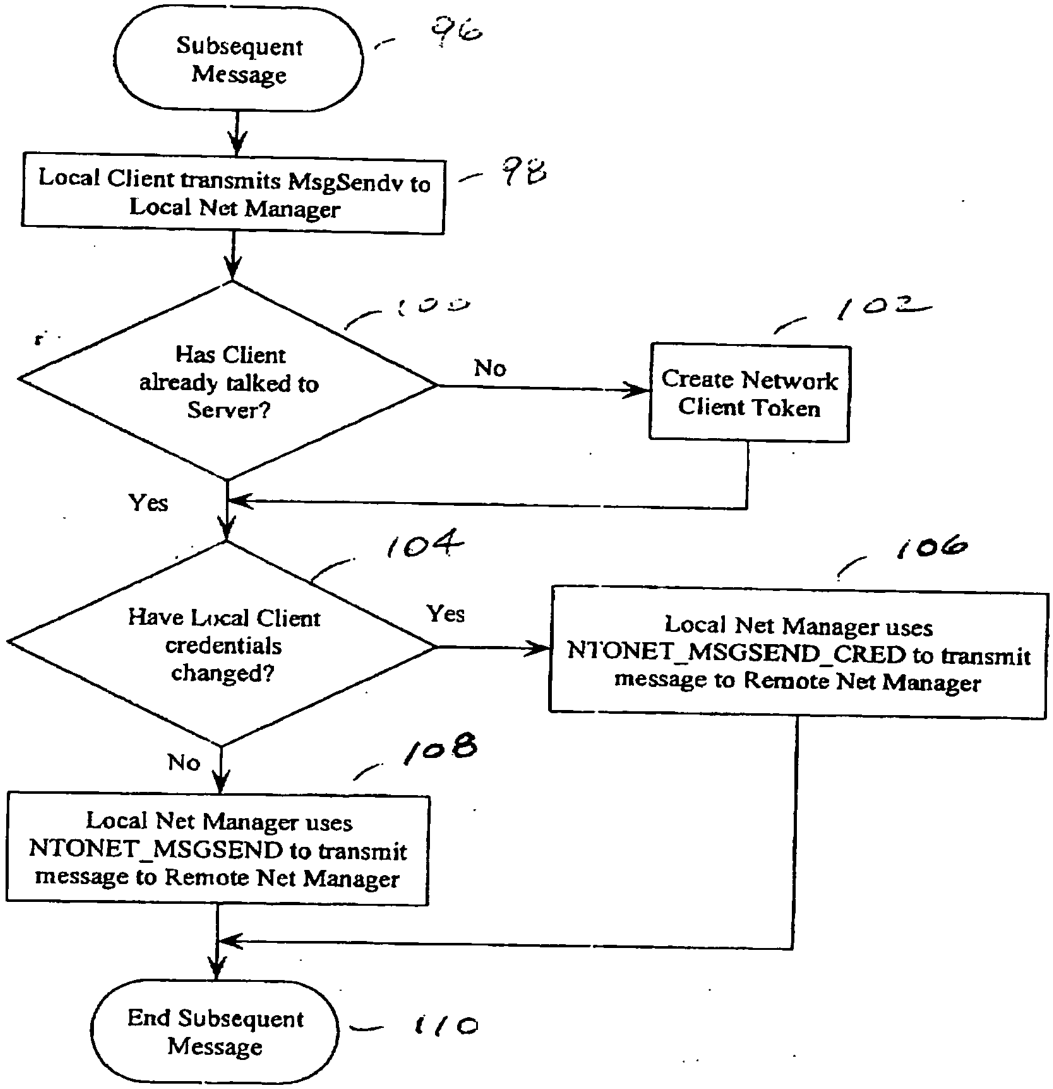
Subsequent Message
96
Local Client transmits MsgSendv to Local Net Manager
98
Has Client already talked to Server?
100
No
Create Network Client Token
102
Yes
Have Local Client credentials changed?
104
Yes
Local Net Manager uses NTONET_MSGSEND_CRED to transmit message to Remote Net Manager
106
No
Local Net Manager uses NTONET_MSGSEND to transmit message to Remote Net Manager
108
End Subsequent Message
110

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FIGURE 7

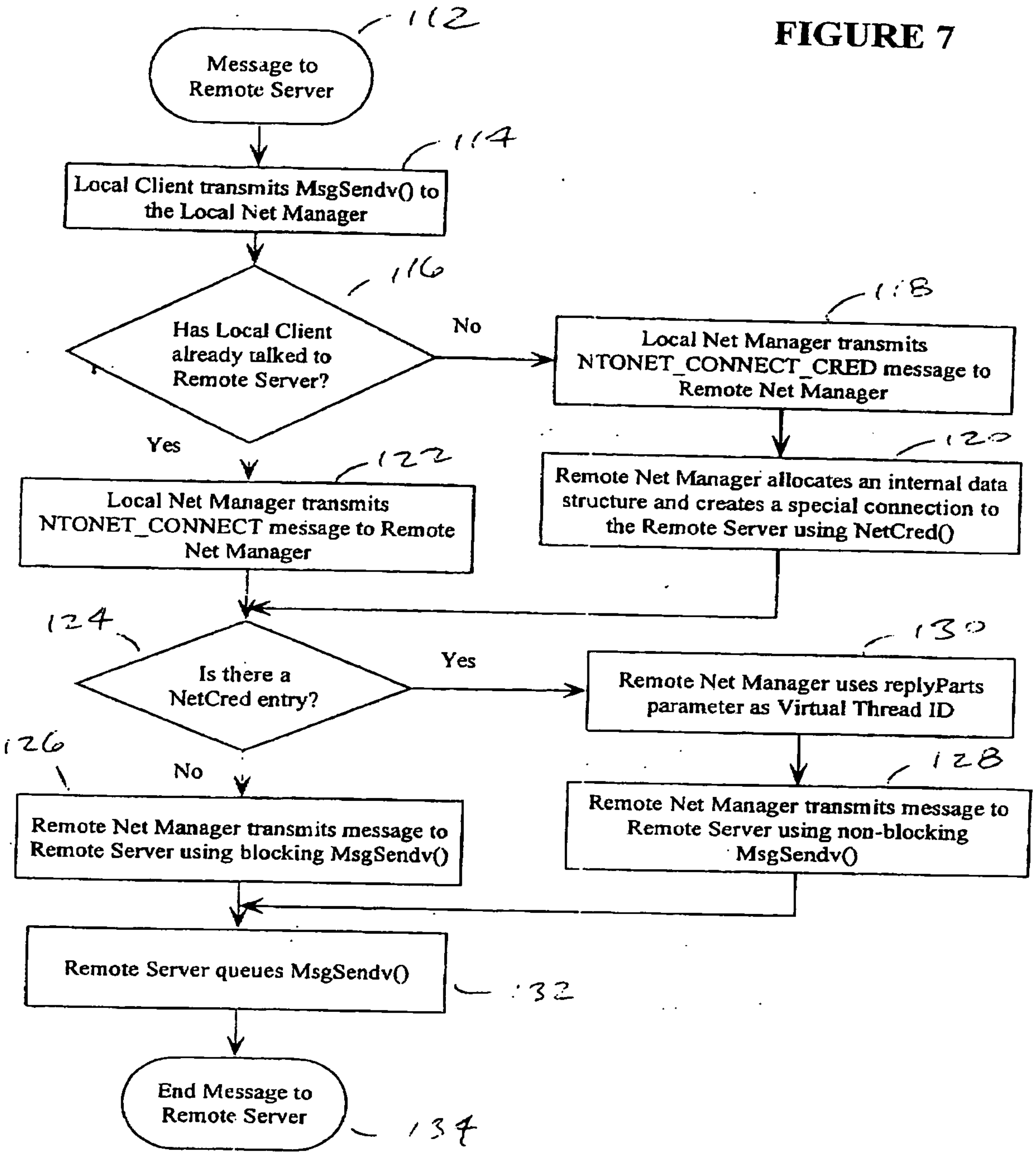
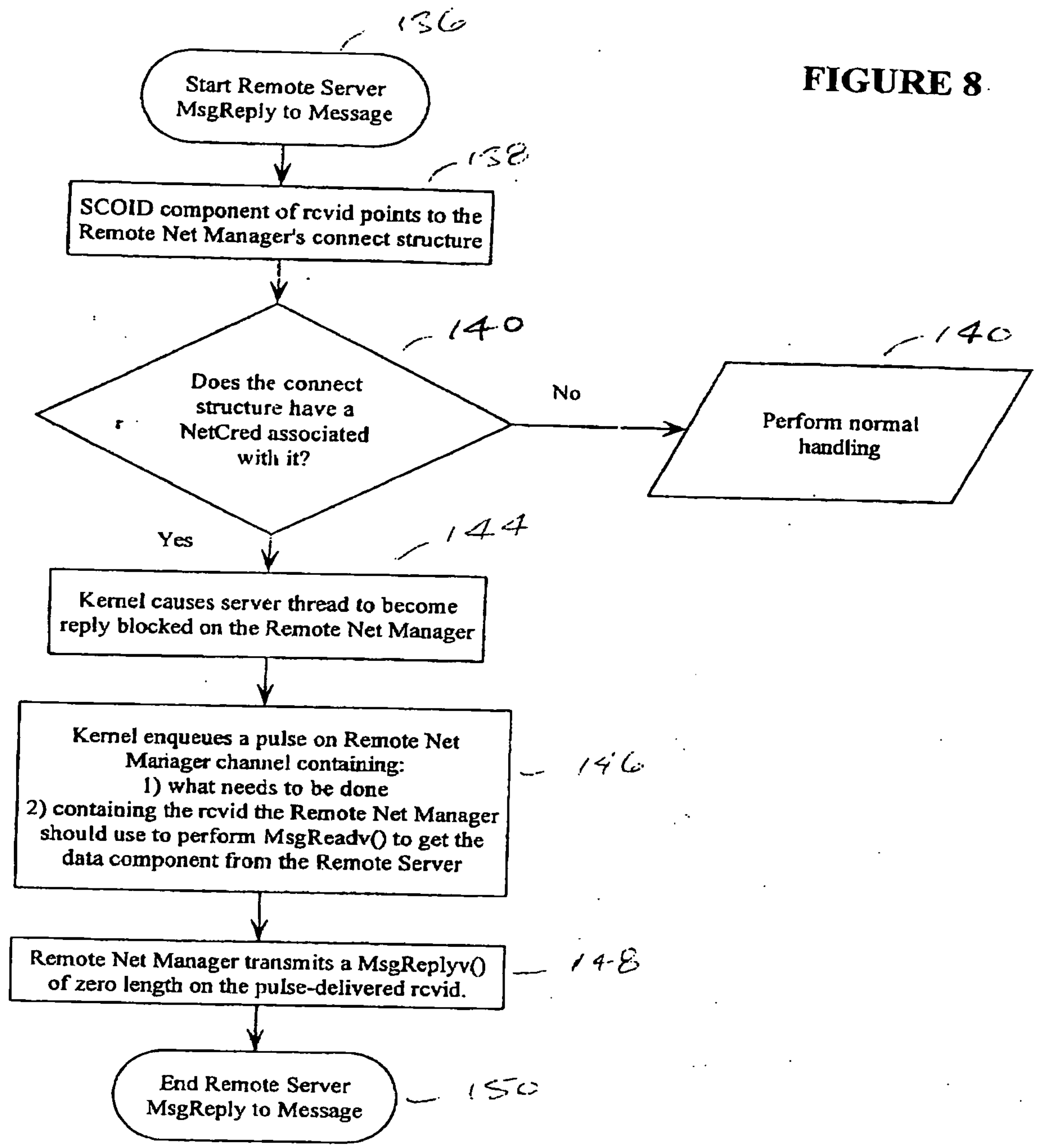


FIGURE 8


136
Start Remote Server MsgReply to Message
138
SCOID component of rcvid points to the Remote Net Manager's connect structure
140
Does the connect structure have a NetCred associated with it?
No
140
Perform normal handling
Yes
144
Kernel causes server thread to become reply blocked on the Remote Net Manager
Kernel enqueues a pulse on Remote Net Manager channel containing:
1) what needs to be done
2) containing the rcvid the Remote Net Manager should use to perform MsgReadv() to get the data component from the Remote Server
146
Remote Net Manager transmits a MsgReplyv() of zero length on the pulse-delivered rcvid.
148
End Remote Server MsgReply to Message
150